PB87-171286

Evaluation of Fabric Filter on Boiler 108 at the Naval Amphibious Base Little Creek, Virginia

ETS, Inc., Roanoke, VA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Mar 87

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA/600/7-87/009
March 1987
PB87-171286

EVALUATION OF FABRIC FILTER ON BOILER 108 AT THE NAVAL AMPHIBIOUS BASE, LITTLE CREEK, VA

by:

JOYCE M. FOSTER
JOHN C. MYCOCK
JOHN W. RICHARDSON
JOHN D. MCKENNA

ETS, INC.
SUITE C-103
3140 CHAPARRAL DR., SW
ROANOKE, VA 24018-4394

EPA CONTRACT NO. 68-02-3939

EPA PROJECT OFFICER:

DALE L. HARMON
AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
RESEARCH TRIANGLE PARK, NC 27711

AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/7-87/009		PB87 171286/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Evaluation of Fabric Filter on Boiler 108 at the Naval Amphibious Base, Little Creek, VA	March 1987
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Joyce M. Foster, John C. Mycock, John W. Richardson, and John D. McKenna	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS ETS, Inc. Suite C-103 3140 Chaparral Drive, SW Roanoke, Virginia 24018-4394	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. 68-02-3939
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Final; 6/83 - 9/86
	14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Dale L. Harmon, Mail Drop 62B, 919/541-2429.

16. ABSTRACT The report gives results of an evaluation of fabric filtration on Boiler 108 at the Naval Amphibious Base (NAB), Little Creek, VA. The operating characteristics of the reverse-air baghouse controlling emissions from Boiler 108 were determined via data (collected by Navy personnel) on boiler and baghouse operation (hours of operation, coal feed rate, steam load, air load, baghouse inlet temperature, and baghouse module pressure drop), and periodic inspection and testing of selected bags. Tests of physical characteristics of the fiberglass bags revealed normal deterioration of fabric strength with increasing time of exposure to flue gas. Fill fibers were more affected than warp fibers. A long plateau in bag life was observed; fabric characteristics after 1500 hours of actual operation and after 7600 hours did not differ greatly. Statistical analyses of fabric test data indicated effects on fabric due both to length of exposure time and position in the baghouse, and interaction of those effects. Other analyses indicated that exposure time was the dominant effect. Operating costs for reverse-air and induced-draft fans were calculated for 1983, 1984, and 1985.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Boilers	Pollution Control	13B
Filtration	Emission	Stationary Sources	07D
Glass Fibers	Coal	Fabric Filters	11E, 11B 21D
Particles	Combustion	Particulate	14G
Dust	Flue Gases		11G
Fly Ash	Operating Costs		21B 14A, 15A
Fans			13A

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	59
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

Periodic testing of physical characteristics of fiberglass bags removed from Baghouse 108 at the Naval Amphibious Base (NAB), Little Creek, VA, after varying times of exposure to flue gas, revealed the gradual decline in physical strength of fibers, particularly fill fibers. Although holes and pearling were noted in some test bags and a thorough inspection of Baghouse 108 revealed acid attack, Baghouse 108 worked well in controlling emissions from Boiler 108 during the course of this study, and as of July 1986, continued in service without visible emissions or pressure drop problems. Bag life in excess of three years installed time has been observed in Baghouse 108.

Costs of operating the induced draft (I.D.) and reverse air (RA) fans were calculated for actual hours of operation during 1983, 1984 and 1985.

TABLE OF CONTENTS

	PAGE
ABSTRACT	iii
TABLE OF CONTENTS	v
LIST OF TABLES	vi
LIST OF FIGURES	vi
ACKNOWLEDGEMENTS	vii
INTRODUCTION	1
DESCRIPTION OF BOILER/BAGHOUSE 108	3
DESIGN OF THE FABRIC TESTING PROGRAM	7
DESCRIPTION OF FABRIC TESTS	12
RESULTS OF FABRIC TESTING PROGRAM	13
NOTES OF A "2-WEEK" VISIT TO NAB, LITTLE CREEK, VA	15
EFFECT OF POSITION AND LENGTH OF EXPOSURE ON FABRIC	34
POWER COSTS	37
CONCLUSIONS	39
REFERENCES	40
APPENDIX - STATISTICAL ANALYSIS	41

Preceding page blank

LIST OF TABLES

	PAGE
TABLE I - BOILER/BAGHOUSE 108 OPERATING INFORMATION.....	6
TABLE II - DATA SUMMARY.....	19
TABLE III - SUMMARY OF FABRIC WEIGHTS.....	25
TABLE IV - SUMMARY OF PHYSICAL CHARACTERISTICS OF TEST BAGS.....	26
TABLE V - INVESTIGATION OF THE EFFECT OF POSITION ON FABRIC TEST VALUES.....	35
TABLE VI - INVESTIGATION OF EFFECT OF LENGTH OF EXPOSURE ON FABRIC TEST VALUES.....	36

LIST OF FIGURES

FIGURE 1 - BOILER/BAGHOUSE 108 PROCESS FLOW DIAGRAM.....	5
FIGURE 2 - ORIGINAL PLAN OF TEST BAG LOCATIONS IN BH 108..	8
FIGURE 3 - ACTUAL LOCATIONS OF TEST BAGS IN BH 108.....	9
FIGURE 4 - MODULE ΔP AT VARYING STEAM LOADS.....	11
FIGURE 5 - ANTICIPATED FABRIC STRENGTH RETENTION VS. EXPOSURE TIME.....	27
FIGURE 6 - PERMEABILITY.....	28
FIGURE 7 - TENSILE - WARP FIBERS.....	29
FIGURE 8 - TENSILE - FILL FIBERS.....	30
FIGURE 9 - MULLEN BURST.....	31
FIGURE 10 - MIT FLEX - WARP FIBERS.....	32
FIGURE 11 - MIT FLEX - FILL FIBERS.....	33

ACKNOWLEDGEMENTS

The authors wish to acknowledge the help of numerous engineering and boiler plant personnel at the Little Creek Naval Base, for their assistance in retrieving the test bags and gathering on-site boiler and baghouse data.

METRIC CONVERSIONS

Readers more familiar with the metric system may use the following values to convert the nonmetric units used elsewhere in this report.

Nonmetric	Times	Yields Metric
acfm	0.000472	m^3/s
°F	5/9 (°F-32)	°C
ft	0.305	m
ft/min	0.00508	m/s
in.	0.0254	m
in. H_2O	0.249	kPa
in. (vac)	3.38	kPa
lb/hr	0.000126	kg/s
lb/in. (Tensile)	175	N/m
oz/yd^2	0.0339	kg/m^2
psi	6.89	kPa
tons/hr	0.252	kg/s

INTRODUCTION

This project was undertaken in order to develop baseline data on the performance and operating characteristics of the Griffin Environmental reverse air baghouse installed on Boiler 108 at the steam plant, Naval Amphibious Base (NAB), Little Creek, VA. Baghouse start-up occurred in August 1983, and from that time until September 1985, some data on fabric filter operation and maintenance were supplied by the Navy. ETS performed physical tests on bags pulled from the baghouse after varying exposure times, in order to monitor wear on the bags and predict bag failure and expected life. Failed bags were analyzed in order to identify cause of failure and to recommend corrective action.

Tasks to be accomplished for this project included:

1. The collection of boiler operating data by Navy personnel:

   Steam flow;
   Air flow;
   Coal analysis;
   Coal-feed rate;
   Firing mode.

2. The collection of baghouse operating data by Navy personnel and by calculation from acceptance tests:

   Pressure drop;
   Inlet gas flow volume and gas-to-cloth ratio;
   Outlet opacity level;
   Inlet and outlet flue gas temperatures.

3. The calculation of fan power consumption.

4. The calculation of cleaning power consumption.

5. Graphic depictions of relationships among parameters (e.g., module pressure drop vs. steam loading).

6. Identification of problems of baghouse operation and maintenance.

ETS was responsible for Items 3-6.

The scope of this report covers the tasks ETS was able to accomplish using available data. Flange-to-flange pressure drop over the entire baghouse on Boiler 108 was measured by magnehelic, but readings were not recorded on boiler log sheets. Rather, individual module pressure drops were recorded. In a telephone conversation, Mr. Jack Maahs, Instrument Mechanic at the NAB heating plant, informed ETS that system pressure drop usually measured 2-4 inches H_2O,* (0-2 inches above the average module pressure drop). Each boxcar-load of coal for the NAB was analyzed, but the reports of analysis were not available to ETS. However, the reason for analysis was to assure that the coal met Navy specifications and Mr. Maahs stated that specifications normally were met.

(*) British units are used throughout this report for the readers convenience. Readers more familiar with metric units may use the conversion table at the end of the front matter.

DESCRIPTION OF BOILER/BAGHOUSE 108

Boiler 108, one of four boilers at the Central Steam Plant, Naval Amphibious Base (NAB), Little Creek, VA, is a spreader-stoker rated at 90,000 lb/hr steam but normally operated at 40,000-60,000 lb/hr. In 1983 the boiler was converted from firing #6 oil to firing coal.

A Griffin Environmental negative pressure, reverse air baghouse (Baghouse 108) controls emissions from Boiler 108. Design specifications[4] for the emissions control system included:

Baghouse:	Flow	49,800 ACFM
	Temperature	350°F (maximum 500°F)
	Pressure drop ($\triangle$ P)	7 inches H_2O (dirty)
	Full load dust loading	1,000 lb/hr
	Gas-to-cloth (G/C) ratio	2.5 max (during cleaning)
	Collection Efficiency	99.9% (by weight)

Coal: Bituminous with maximum 1.5% sulfur (S). Each boxcar-load of coal received at the NAB, Little Creek, was analyzed either by Levisa Testing Co., Grundy, VA, or Standard Labs, Inc. Sources of coal for NAB, Little Creek were International Resources, Inc. of Knoxville, TN and San Juan Coal Sales of Matawan, NJ. Generally coal specifications were met, according to Mr. Jack Maahs of the NAB.

Bags: Woven fiberglass with a coating of Teflon B for 10% add-on weight, or a combination coating of silicon graphite and Teflon. Fabric weight of 14 oz/yd^2 minimum, with a permeability of 60 ft/min. Bags were rated for maximum operating temperature of 500°F. Bags were 25 feet in length, 8 inches in diameter.

Bag spacing inside the baghouse was 2 inches. Anti-collapse rings were sewn into the bags at 4 or 5-foot intervals.

Cleaning: Baghouse 108 had an optional pressure drop-triggered cleaning control (set at 6 inches H_2O) but normally cleaned twice every 24 hours on a timing cycle. During the winter, cleaning could occur three times per 24-hour period. Baghouse 108 was equipped with an automatic, pressurized fly ash handling system.

Figure 1 describes the process flow for Baghouse 108.

Table I summarizes boiler and baghouse operating data collected during the period of testing for this contract.

Typical gas flow at full boiler load for Baghouse 108 was determined during acceptance testing (12/10/83)[1] to be 47,561 ACFM @ 371°F.

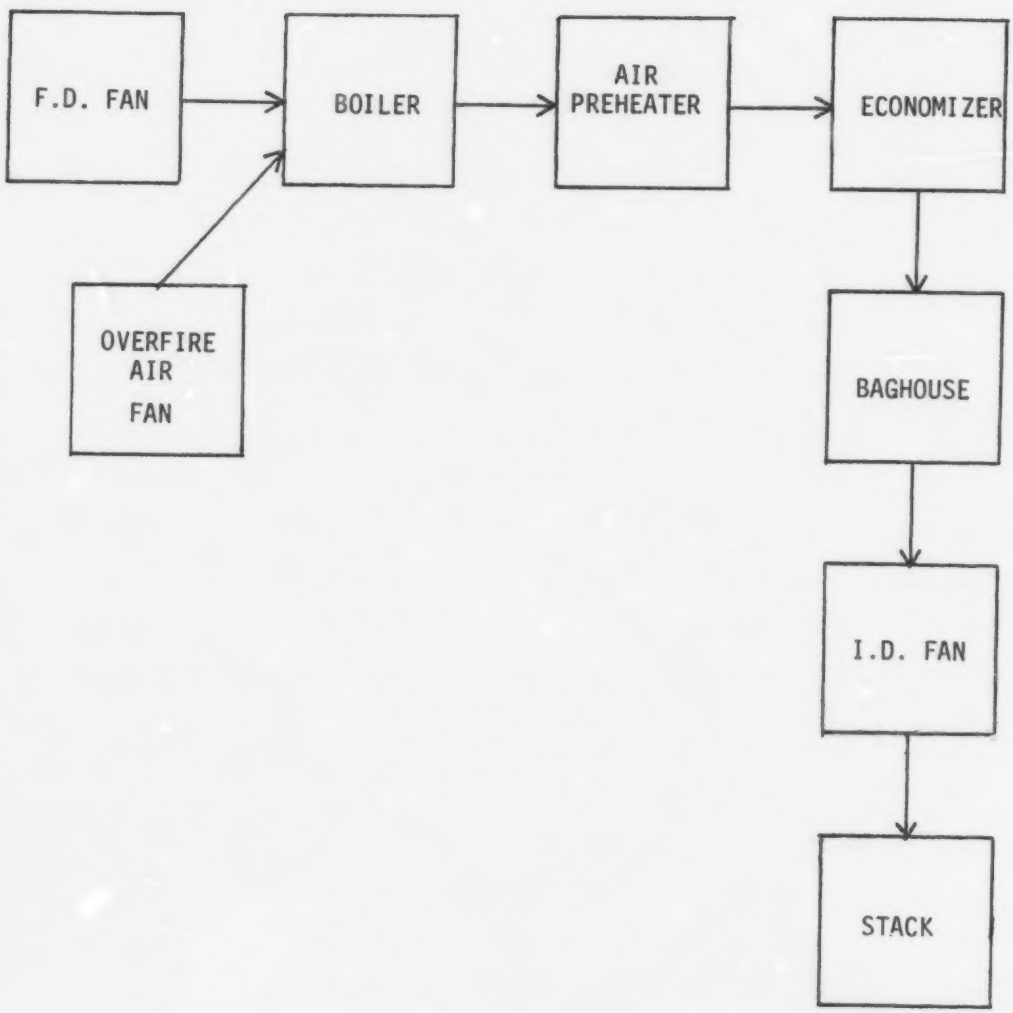


FIGURE 1

BOILER/BAGHOUSE 108 PROCESS FLOW DIAGRAM
CENTRAL STEAM PLANT, NAB, LITTLE CREEK, VA

TABLE I

BOILER/BAGHOUSE 108 OPERATING INFORMATION, MONTHLY AVERAGES

DATE	APPROXIMATE OPERATING TIME	COAL BURNED, AVG TPH	STEAM, 1000 LBS/HR	AIR, 1000 LBS/HR	BAGHOUSE TEMPERATURE, °F INLET LOW	INLET HIGH	INLET AVG	OUTLET LOW	OUTLET HIGH	OUTLET AVG	BAGHOUSE MODULE ΔP, INCHES H_2O 1	2	3	4	5	6
09/85	64 HRS	2.236	61	69	312	326	320	242	271	260	1.7	1.6	1.3	1.6	1.6	1.3
05/85	118 HRS	2.150	63	72	317	327	322	261	273	268	1.6	1.9	2.0	2.3	1.5	1.9
04/85	253 HRS	2.118														
03/85	616 HRS	2.425	55	73	322	337	330	257	275	268	2.1	2.3	2.4	2.6	2.0	2.3
02/85	415 HRS	2.661	63	84	340	360	354	270	290	282	3.0	3.4	3.5	3.5	2.8	3.1
01/85	536 HRS	2.638	63	82	341	358	350				2.2	2.7	2.7	2.2	2.3	2.6
12/84	595 HRS	2.413	54	74	333	358	346				2.1	2.1	2.2	1.8	2.0	2.3
11/84	398 HRS	2.324	56	75	349	365	357				2.1	2.2	2.4	1.8	2.0	2.4
09/84	154 HRS	2.553	62	75	344	363	353				1.8	1.9	2.0	1.6	1.6	1.9
08/84	656 HRS	2.572	62	84	343	362	354				1.6	1.9	2.0	1.6	1.6	2.0
07/84	213 HRS	2.590	64	89	345	363	354	296	319	310	2.1	2.2	2.2	1.7	1.6	1.8
05/84	349 HRS	3.129	75	95							2.0	2.2	2.3	2.1	1.9	2.2
04/84	614 HRS	2.535	58	82							OVERALL AVERAGES					
03/84	204 HRS	2.810	66	84												
02/84	301 HRS	2.763	64	83							TPH = tons per hour					
01/84	597 HRS	2.465	58	77												
12/83	445 HRS	2.708	63	82												
11/83	351 HRS	2.484	53	68												
10/83	345 HRS	2.851	56	68							(DATA MISSING FROM TABLE I WERE NOT COLLECTED)					
08/83	378 HRS	2.414	43	55												

DESIGN OF THE FABRIC TESTING PROGRAM

The bag evaluation portion of this contract was originally designed as follows:

Bag Pull	No. of Bags to be Extracted	Length of Time in Service
1	9	2 weeks
2	9	1 month
3	9	3 months
4	9	6 months
5	9	9 months
6	9	12 months
TOTAL	54	

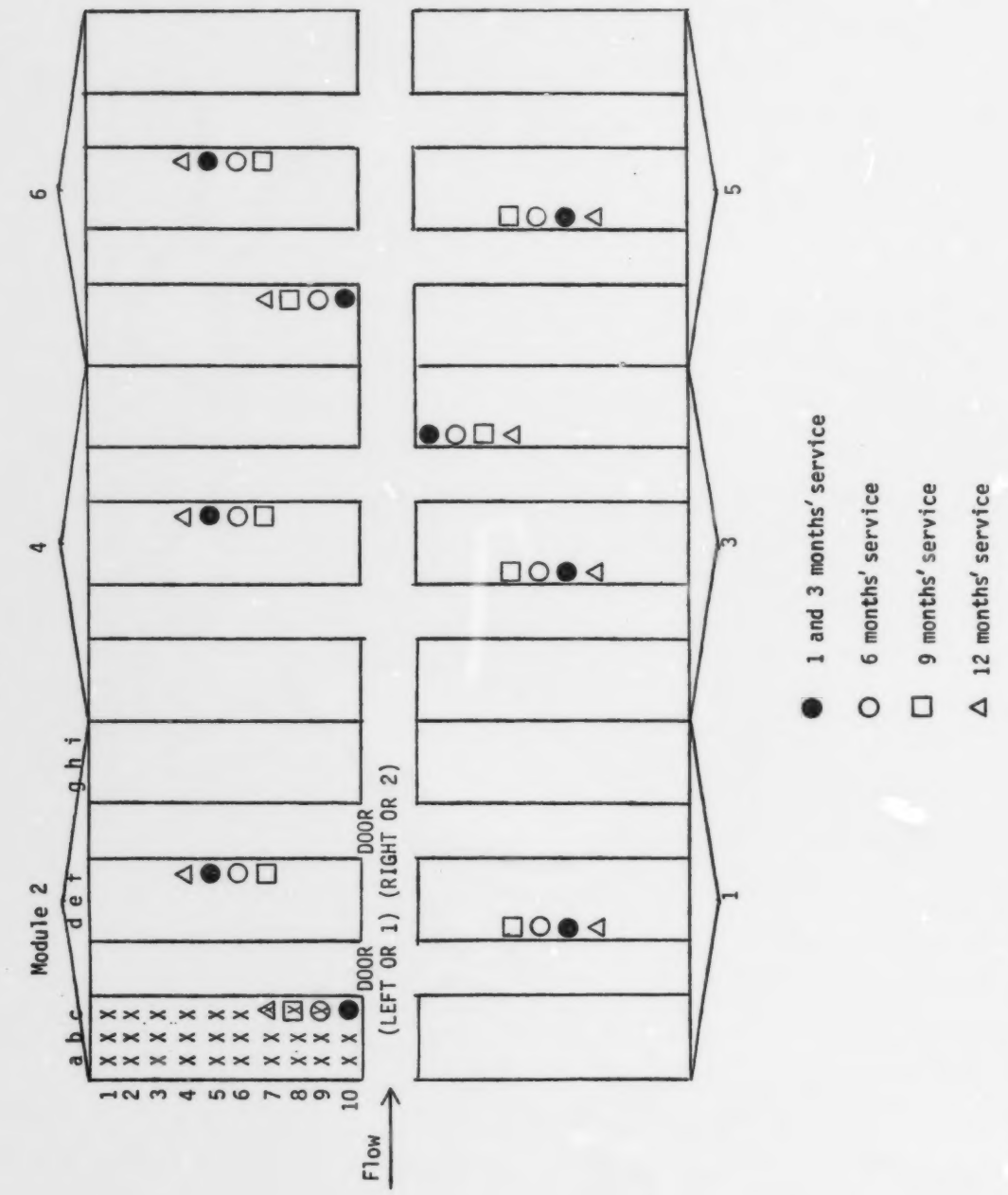
In addition, three unused bags would be subjected to the same fabric tests.

Figure 2 shows the original designation of test bag locations in Baghouse 108. These locations were chosen to ensure the testing of typical average bags (those near the center of each module) and possible worst-case bags (three locations near doors in case of leakage around doors).

Figure 3 shows the actual locations of test bags in Baghouse 108. Three new, unused bags were tested, as well as three bags exposed to flue gas but never actually in service in the baghouse.

FIGURE 2

ORIGINAL PLAN OF TEST BAG LOCATIONS IN BAGHOUSE 108



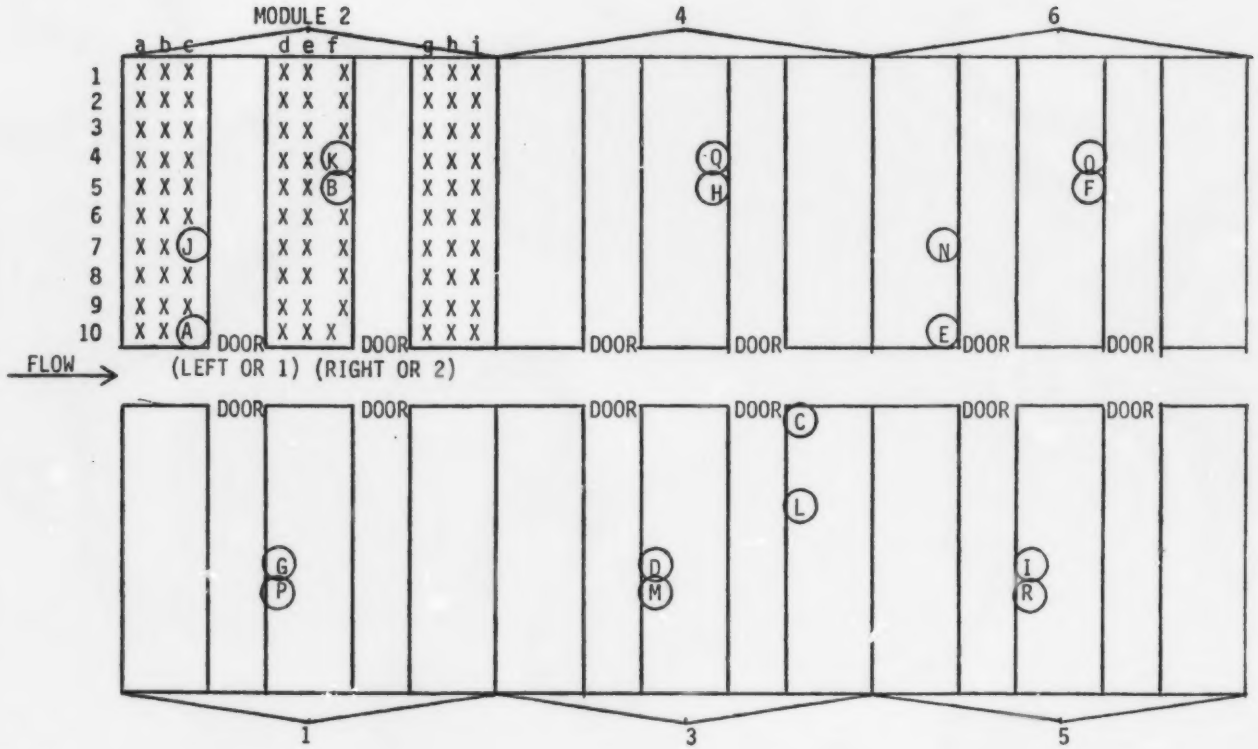


FIGURE 3

ACTUAL LOCATIONS OF TEST BAGS IN BAGHOUSE 108

ETS I. D. Numbers:

	Series I	Series II	Series III	Series IV		Series V
A:	626DB	773DB	819DB	1096DB	J:	2223DB
B:	621DB	774DB	818DB	1099DB	K:	2215DB
C:	623DB	775DB	820DB	1098DB	L:	2222DB
D:	625DB	772DB or 778DB	824DB	1097DB	M:	2221DB
E:	622DB	776DB	821DB	1092DB	N:	2219DB
F:	624DB	772DB or 778DB	825DB	1093DB	O:	2220DB
G:	628DB	779DB		1100DB	P:	2216DB
H:	629DB	777DB	822DB	1094DB	Q:	2217DB
I:	627DB	780DB	823DB	1095DB	R:	2218DB

Figure 4 depicts graphically the clustering of operating levels at about 54,000 lb/hr and 62,000 lb/hr steam, as well as the spike in module $\triangle P$ during January and February 1985, also seen in the data in Table I.

The fabric tests chosen were:

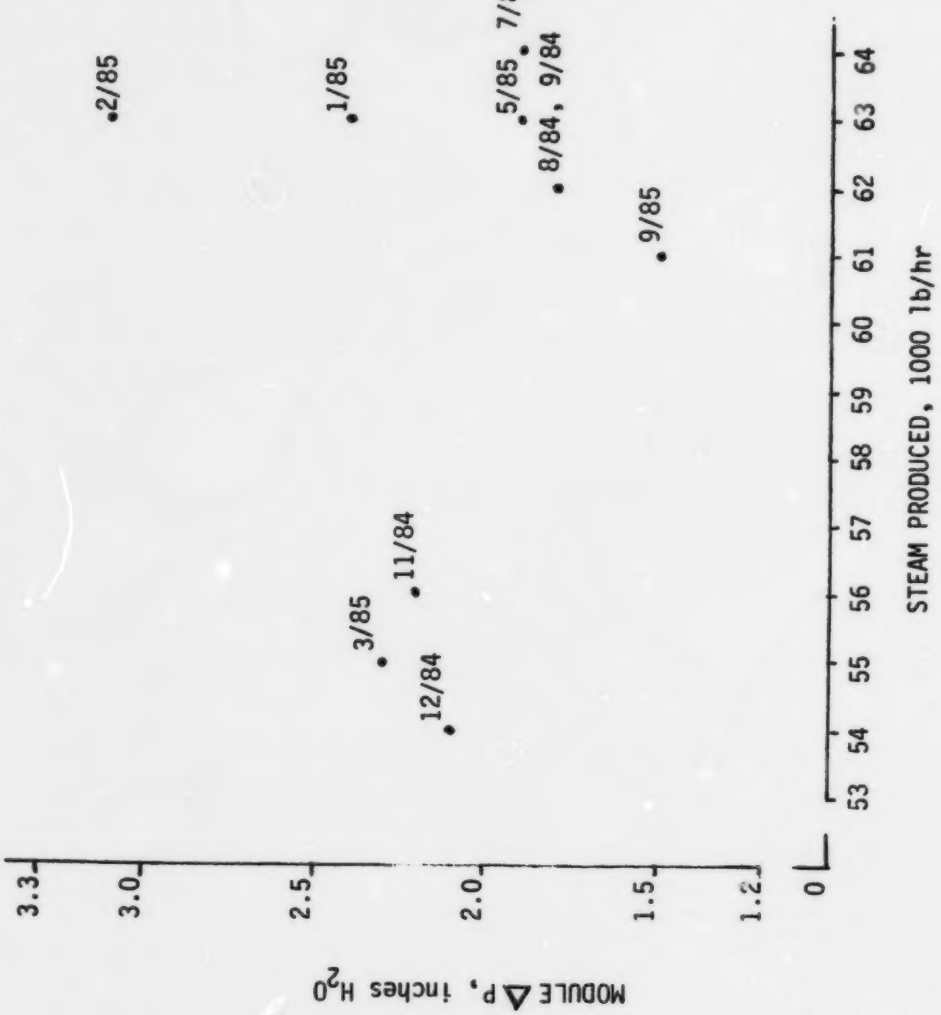
- Permeability, as received and after 10" and 30" vacuuming (ASTM D737-75 1980)
- Tensile Strength (ASTM 1682-64 1975)
- Mullen Burst (ASTM D3786-80A)
- Organic Content (Loss on Ignition) (ASTM D578-83)
- MIT Flex (ASTM D2176-69 1982) before acid treatment.

Fabric weights as received and after vacuuming were recorded.

Visual and microscopic examinations of selected bags were performed by ETS laboratory personnel.

FIGURE 4

MODULE ΔP AT VARYING STEAM LOADS



DESCRIPTION OF FABRIC TESTS

Permeability is a measure of the air handling capability of filter media. It monitors the compliance of new fabrics with purchase specifications and the degree of blinding of used fabrics.

The Tensile Strength test measures stretch, elongation and tear characteristics of fabrics, and relative strength of warp and fill yarns in fabrics.

The MIT Flex test measures the relative ability of fiberglass fabric weaves and finishes to withstand self-abrasion from flexing.

The Mullen Burst test measures the relative total strength of fabrics to withstand severe pulsing or pressure.

RESULTS OF FABRIC TESTING PROGRAM

Test bags were 3 x 1 twill, woven fiberglass with about 5% organic finish according to Loss on Ignition (LOI) test results. Bag dimensions were 8" diameter and 25' length.

Results of visual and microscopic examination of test bags follow:

New Bags

- When pulled slightly, fibers in fill direction along seam came apart leaving sizable holes.

Bags Exposed Only to Gas

- Slight pull in horizontal direction caused holes along seam.
- Seam was abraded all along length of one bag, whose cap was incorrectly seated.

Series I

- Diamond collapse pattern seen often. Some dust on outside of bags. Dust cake black, sometimes regular, sometimes irregular in pattern, with slight to moderate pearling especially in bottom section of bag. Slight damage to warp fibers at seam, and opposite the seam in 4 bags. Often slight damage to warp fibers observed at ring cover. Perhaps unburned coal present. Some holes observed.

- At 100X

  Fill side a little dirtier than warp side after vacuuming, but cleaned fairly well. Large pearls on one bag.

Series II

- Black dust, some of it on outside of 2 bags. One bag also had patches of brown and white dust. Slight damage to warp fibers along seam. Wear in area of ring cover. Diamond collapse pattern found in 8 bags. Slight to moderate pearling in 3 bags. Some holes observed.

- At 100X

  Cenospheres observed - white, amber, black; some were smooth but most black cenospheres were irregular in shape. After vacuuming, fill threads dirtier than warp.

Series III

- Fine black dust, cake fairly even. Slight warp fiber damage along seam, sometimes opposite seam. Cuff wear at ring cover. Rusty caps on some bags.

- At 100X

  Fewer black particles in dust than in Series I and II. Cenospheres observed. After 30" vacuum, fill threads remained dirtier than warp, but bag had cleaned moderately well.

Series IV

- Black, gray, brown dusts present. Cap bent on 1 bag, rusty on 3 bags. Slight wear at ring cover. Rings bent into oval shape. Wear at seam and cuff on a few bags. Some holes found. Slight pearling, especially in bottom section, on 4 bags.

- At 100X
  50% black dust, 50% light gray dust. Similar to Series III dust. Black, white and amber cenospheres. Fill fibers dirtier than warp after vacuuming. Bags were cleaner after vacuuming than Series III bags.

Series V

- Warp damage along seams. Caps rusty on 5 bags. Rings bent in oval shape, all had weld bumps. Black dust. Some pearls.

The following report of an inspection of Baghouse 108 gave evidence of acid attack.

NOTES ON A "2-WEEK" VISIT TO NAB, LITTLE CREEK, VA

ETS personnel visited the Naval Amphibious Base, Little Creek, Virginia on September 7 and 8, 1983. They performed a thorough inspection of each module of Baghouse 108. Each module was entered and conditions such as ash build-up, bag holes, acid attack, etc., were noted.

An inspection of the lower section of Module 1 revealed that a tube band had slipped and ash had accumulated at the base of several bags in Row G. Ash build-up also was noted at the base of bag 9 in Row D of this module.

The inside of the door of Module 2 showed signs of acid attack. Bags 8, 9 and 10 of Row F also showed some signs of condensation, with an ash cake on the outside of the lower parts of the bags. Some condensation tracks were seen around the door which appeared to have been caused by an improper door seal.

No problems were noted in the lower sections of Modules 3 and 4. Ash build-up in these sections ranged from 1/2" to 1/8".

Very heavy ash build-up was detected in the lower section of Module 5 around bags 8, 9 and 10 of Row G. Bag 10 of Row G seemed somewhat more loose than the other bags.

Ash build-up also was observed around bags 6, 7 and 8 in Row D. Some tracks of acid condensation were seen in the lower section of Module 5, perhaps occurring at start-up.

Some evidence of acid condensation also was detected in Module 6.

No problems were noted during a walk-through inspection of the upper levels of Modules 1, 2 and 4. It appears that all bags that are located near the hand rails adjacent to the doors have touched the hand rails at one time or another. Marks on the bags were observed approximately 34" from the walkway, which is the same height as the handrail.

Acid condensation was observed on bags 8, 9 and 10 of Row G at the upper level of Module 5. Ash cake was noted on these bags and the door.

Bags 7, 8, 9 and 10 of Row G, Module 6, also showed evidence of acid condensation. The door near Rows G, H and I showed signs of considerable acid attack, while the door near Rows A, B and C showed no evidence of acid attack. Gasket material around all doors showed some evidence of acid attack and had begun to erode.

It appeared from the presence of pearling in the dust cake on the bags and the evidence of acid attack inside the baghouse, that condensation was a problem inside Baghouse 108.

Table II contains the average results of all fabric tests performed on each series of bags pulled.

Table III summarizes fabric weight data. Fabric weights varied little from one series of test bags to another, but Table IV reveals a decline in fabric strength over time, particularly for fill fibers, in Series IV (approximately 1500 hours of on-line service) and Series V (approximately 7600 hours). Permeability did not recover after vacuuming to new-bag levels for any of the series of test bags.

Figure 5 presents graphically the decline of fabric strength with increasing exposure time. Only the shape of the curve is of interest; individual fabric tests varied greatly in retained fabric strength but generally followed the shape of the curve in Figure 5 (see Figures 6, 7, 8, 9, 10 and 11, which were prepared from the data in Table IV).

ETS personnel performed a statistical analysis of data from this project, including fabric tests, position in the baghouse and length of exposure time, in order to gauge the effects of baghouse position and exposure time on fabric test results. Generally, both baghouse position and exposure time had effects on fabric test results, and there was interaction between those effects. The complete report of statistical analysis may be found in the Appendix.

TABLE II
DATA SUMMARY

(average values)

ID NOS.		PERMEABILITY (FT/MIN)			MULLEN BURST (PSI)	TENSILE (LB/IN)		MIT FLEX (# FLEXES TO FAILURE)		LOSS ON IGNITION (%)
ETS I.D.	NAVY I.D.	AS REC'D	10" VAC	30" VAC		WARP	FILL	WARP	FILL	
576 CB	New	66.5			621	478	265	4635	927	4.8
577 CB	New	61.5			494	429	217	4359	1280	4.5
578 CB	New	65.0			517	436	223	2882	1175	4.3
579 DB	Exposed to gas	60.8			685	473	258	4103	1401	4.2
580 DB	Exposed to gas	61.1			717	>500	262	5083	1329	4.5
581 DB	Exposed to gas	60.0			683	462	251	3497	747	4.0

TABLE II (CON'T.)
DATA SUMMARY

(average values)

ID NOS. ETS I.D.	ID NOS. NAVY I.D.	PERMEABILITY (FT/MIN) AS REC'D	PERMEABILITY (FT/MIN) 10" VAC	PERMEABILITY (FT/MIN) 30" VAC	MULLEN BURST (PSI)	TENSILE (LB/IN) WARP	TENSILE (LB/IN) FILL	MIT FLEX (# FLEXES TO FAILURE) WARP	MIT FLEX (# FLEXES TO FAILURE) FILL	LOSS ON IGNITION (%)
SERIES I										
626DB	MOD 2 COMP C BAG 10	5.3	23.2	29.9	519	401	235	6291	1061	
621DB	MOD 2 COMP F BAG 5	5.7	23.9	30.9	524	420	240	7092	725	
623DB	MOD 3 COMP C BAG 10	5.0	24.3	31.2	550	381	240	6532	1255	
625DB	MOD 3 COMP F BAG 5	4.3	23.1	32.5	541	~500	298	8644	1229	4.2
622DB	MOD 6 COMP C BAG 10	5.0	24.5	32.6	528	392	210	6346	1072	
624DB	MOD 6 COMP F BAG 5	4.0	20.5	29.2	517	448	235	7018	1149	3.7
628DB	MOD 1 COMP F BAG 5	4.3	21.5	30.6	504	464	248	6531	1029	4.0
629DB	MOD 4 COMP F BAG 5	3.7	18.8	27.9	517	470	236	7888	856	
627DB	MOD 5 COMP F BAG 5	3.3	15.8	23.4	529	~500	270	11526	1107	

TABLE II (CON'T.)
DATA SUMMARY

(average values)

ID NOS.		PERMEABILITY (FT/MIN)			MULLEN BURST (PSI)	TENSILE (LB/IN)		MIT FLEX (# FLEXES TO FAILURE)		LOSS ON IGNITION (%)
ETS I.D.	NAVY I.D.	AS REC'D	10" VAC	30" VAC		WARP	FILL	WARP	FILL	
SERIES II										
773DB	MOD 2 LEFT 1ST BAG	5.2	11.2	18.5	527	388	221	3723	452	4.0
774DB	MOD 2 RIGHT 6TH BAG	3.6	21.4	29.5	479	382	194	5120	779	3.2
775DB	MOD 3 LEFT, 1 ON LEFT	5.3	16.3	23.6	468	384	169	3638	656	3.7
776DB	MOD 6 LEFT, 1ST ON LEFT	4.9	10.0	16.4	568	443	222	4479	787	3.9
772DB	MOD 6 RIGHT DR, 6 LEFT	4.0	18.4	27.5	450	353	190	3365	393	3.5
778DB	MOD 6 RIGHT DR, 6 LEFT	3.4	19.2	28.4	454	404	202	2458	307	3.5
779DB	MOD 1 6 LEFT	5.1	11.6	22.0	504	411	214	5135	951	3.7
777DB	MOD 4 6 LEFT	3.5	17.4	24.2	472	415	212	2450	276	3.8
780DB	MOD 5 6 LEFT	4.5	7.3	14.7	475	391	218	5718	819	3.6

TABLE II (CON'T.)
DATA SUMMARY

(average values)

ID NOS. ETS I.D.	ID NOS. NAVY I.D.	PERMEABILITY (FT/MIN) AS REC'D	PERMEABILITY (FT/MIN) 10" VAC	PERMEABILITY (FT/MIN) 30" VAC	MULLEN BURST (PSI)	TENSILE (LB/IN) WARP	TENSILE (LB/IN) FILL	MIT FLEX (# FLEXES TO FAILURE) WARP	MIT FLEX (# FLEXES TO FAILURE) FILL	LOSS ON IGNITION (%)
SERIES III										
819DB	MOD 2 COMP C BAG 10	3.8	29.5	40.8	428	389	222	2820	716	3.7
818DB	MOD 2 COMP F BAG 5	4.6	26.3	36.6	492	416	212	2544	456	
820DB	MOD 3 COMP C BAG 10	4.6	25.6	39	456	386	174	2761	490	4.3
824DB	MOD 3 COMP F BAG 5	6.5	29.0	38.8	485	422	220	3776	523	4.1
821DB	MOD 6 COMP C BAG 10	3.4	27.4	36.4	484	414	228	3247	558	4.5
825DB	MOD 6 COMP F BAG 5	2.3	11.7	23.3	464	404	214	2515	365	
---	MOD 1 COMP F BAG 5									
822DB	MOD 4 COMP F BAG 5	4.0	24.0	35.7	478	412	214	3272	591	
823DB	MOD 5 COMP F BAG 5	3.9	17.6	29.6	477	402	223	2792	347	

TABLE II (CON'T.)
DATA SUMMARY

(average values)

ID NOS.		PERMEABILITY (FT/MIN)			MULLEN BURST (PSI)	TENSILE (LB/IN)		MIT FLEX (# FLEXES TO FAILURE)		LOSS ON IGNITION (%)
ETS I.D.	NAVY I.D.	AS REC'D	10" VAC	30" VAC		WARP	FILL	WARP	FILL	
SERIES IV										
1096DB	MOD 2 COMP C BAG 10	4.0	24.7	38.3	433	310	125	940	135	
1099DB	MOD 2 COMP F BAG 5	5.3	20.1	30.5	376	343	168	1245	191	
1098DB	MOD 3 COMP C BAG 10	4.0	19.5	31.6	388	320	156	1170	148	
1097DB	MOD 3 COMP F BAG 5	3.9	17.8	29.1	349	296	152	946	178	4.3
1092DB	MOD 6 COMP C BAG 10	7.5	35.8	44.7	344	230	106	652	129	
1093DB	MOD 6 COMP F BAG 5	5.4	35.2	66.8	358	237	147	1160	172	
1100DB	MOD 1 COMP F BAG 5	3.9	20.5	32.4	392	278	149	772	140	4.3
1094DB	MOD 4 COMP F BAG 5	5.2	39.2	71.6	393	255	152	887	153	
1095DB	MOD 5 COMP F BAG 5	4.7	32.4	44.0	367	271	143	505	84	3.3

TABLE II (CON'T.)
DATA SUMMARY

(average values)

ID NOS.		PERMEABILITY (FT/MIN)			MULLEN BURST (PSI)	TENSILE (LB/IN)		MIT FLEX (# FLEXES TO FAILURE)		LOSS ON IGNITION (%)
ETS I.D.	NAVY I.D.	AS REC'D	10" VAC	30" VAC		WARP	FILL	WARP	FILL	
SERIES V										
	MOD 2 DOOR 1									
2223DB	BAG 4(LEFT)	4.1	10.8	20.5	386	265	155	2084	261	
	MOD 2 DOOR 2									
2215DB	BAG 7(LEFT)	4.1	15.7	27.6	432	267	152	1090	185	
	MOD 3 DOOR LEFT									
2222DB	BAG 4(LEFT)	5.1	16.5	32.1	369	270	180	1108	172	
	MOD 3 DOOR RIGHT									
2221DB	BAG 7(LEFT)	4.7	11.7	21.5	345	219	134	1174	160	
	MOD 6 DOOR LEFT									
2219DB	BAG 4(LEFT)	4.1	10.9	22.2	359	224	133	1092	157	
	MOD 6 DOOR RIGHT									
2220DB	BAG 7(LEFT)	3.5	12.0	24.2	331	255	132	1336	180	
	MOD 1 DOOR 1									
2216DB	BAG 7(LEFT)	4.5	23.6	36.4	380	236	130	713	149	
	MOD 4 DOOR RIGHT									
2217DB	BAG 7(LEFT)	5.5	30.4	39.9	359	269	137	458	106	
	MOD 5 DOOR RIGHT									
2218DB	BAG 7(LEFT)	4.0	23.2	33.6	342	280	148	736	86	

TABLE III
SUMMARY OF FABRIC WEIGHTS

	ETS I.D.	FABRIC WEIGHT, OZ/YD² AS RECEIVED	FABRIC WEIGHT, OZ/YD² AFTER 30" VACUUM
SERIES I	626 DB	21.1	13.4
	621 DB	--	13.8
	623 DB	16.1	13.9
	625 DB	18.4	14.0
	622 DB	17.9	13.5
	624 DB	18.7	13.8
	628 DB	17.4	13.8
	629 DB	18.9	14.1
	627 DB	19.3	14.2
SERIES II	773 DB	17.2	14.2
	774 DB	19.0	14.0
	775 DB	17.8	14.2
	776 DB	18.0	14.3
	772 DB	17.7	14.1
	778 DB	18.9	14.1
	779 DB	17.2	14.2
	777 DB	19.3	14.3
	780 DB	18.5	14.5
SERIES III	819 DB	21.4	14.6
	818 DB	--	13.7
	820 DB	16.1	14.9
	824 DB	--	14.6
	821 DB	--	14.6
	825 DB	24.4	14.2
	822 DB	--	14.1
	823 DB	--	14.1
SERIES IV	1096 DB	19.1	14.7
	1099 DB	--	--
	1098 DB	19.6	--
	1097 DB	--	--
	1092 DB	--	14.4
	1093 DB	19.2	14.1
	1100 DB	--	--
	1094 DB	--	14.0
	1095 DB	--	14.1
SERIES V	2223 DB	--	14.4
	2215 DB	--	14.1
	2222 DB	--	14.4
	2221 DB	--	14.5
	2219 DB	--	14.6
	2220 DB	--	14.3

TABLE IV

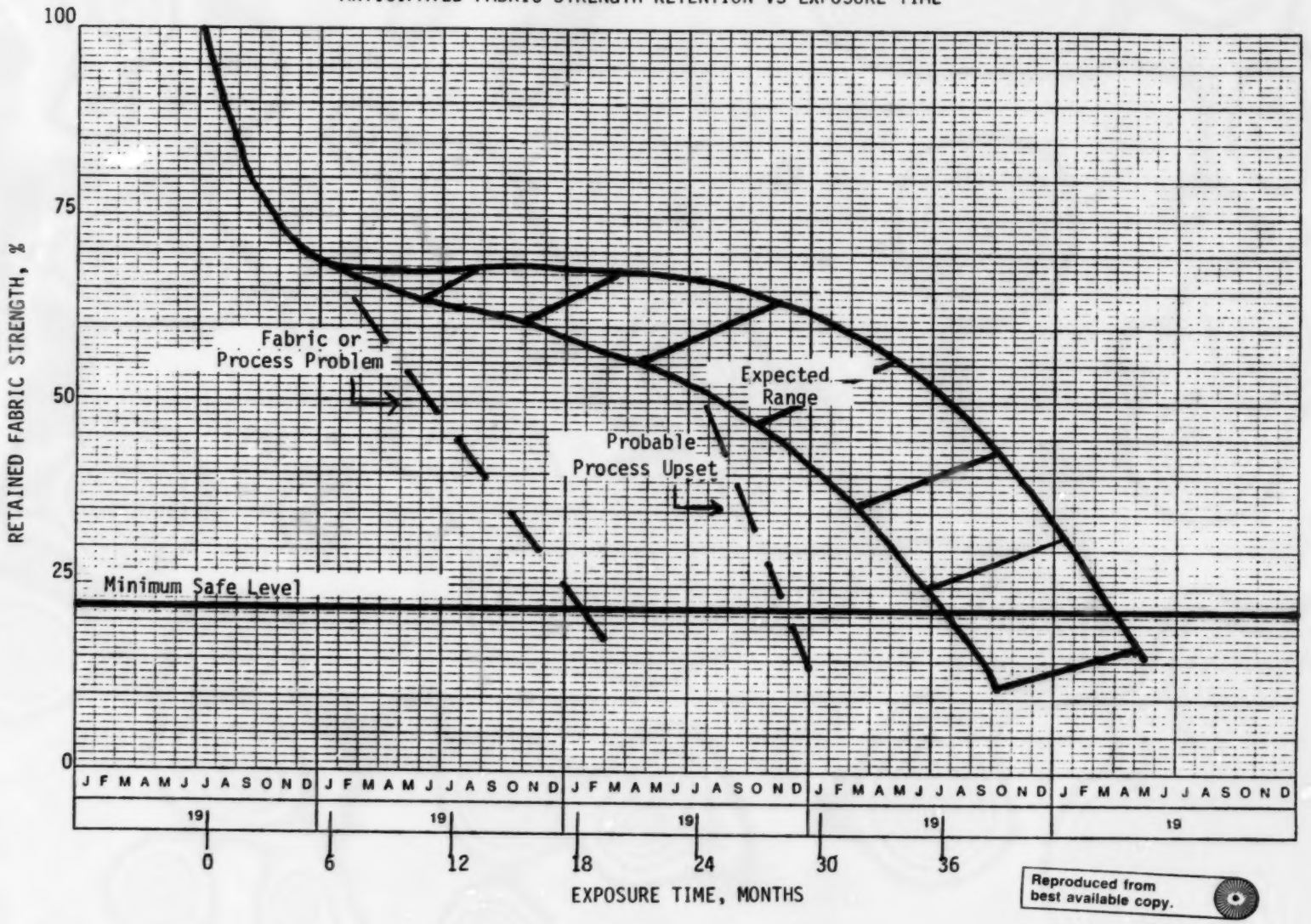
SUMMARY OF PHYSICAL CHARACTERISTICS OF TEST BAGS

(Expressed as % of New Bag Values)

SERIES	DATE PULLED	DATE REC'D	ACTUAL OPERATING TIME, HR	PERMEABILITY AS REC'D	PERMEABILITY VACUUM 10"	PERMEABILITY VACUUM 30"	MULLEN BURST	TENSILE STRENGTH WARP	TENSILE STRENGTH FILL	MIT FLEX WARP	MIT FLEX FILL	LOSS ON IGNITION
I	09/07/83	09/09/83	378	7	34	46	96	99	105	190	94	89
II	11/08/83	11/18/83	513	7	23	36	90	89	87	101	54	82
III	01/24/84	01/26/84	1189	6	37	54	86	91	91	75	45	93
IV	after 05/15/84	06/08/84	1504	8	42	67	70	63	61	23	13	89
V	after 09/27/85	10/24/85	7602	7	27	45	68	57	62	28	14	109

Figure 5

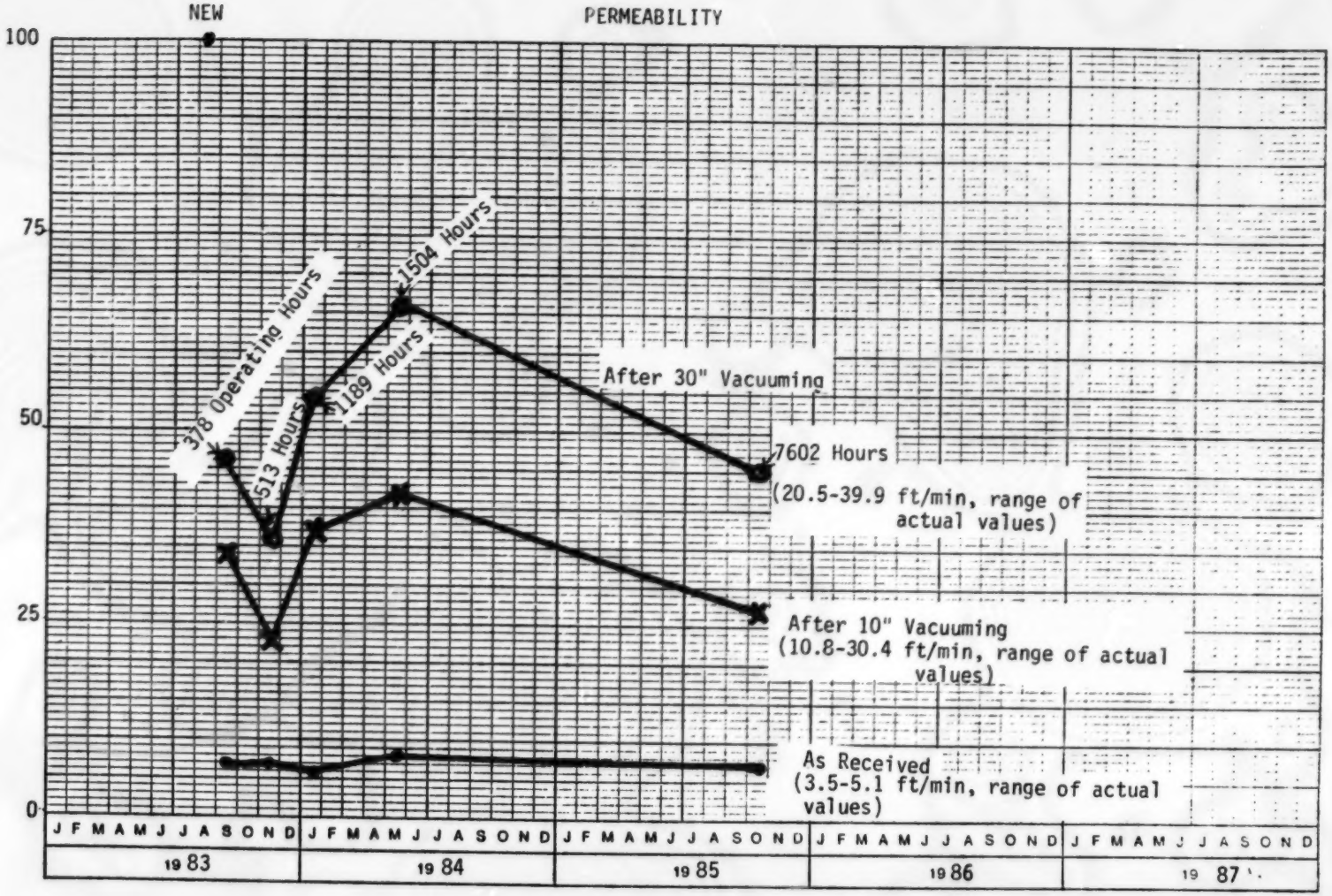
ANTICIPATED FABRIC STRENGTH RETENTION VS EXPOSURE TIME



Reproduced from
best available copy.

Figure 6

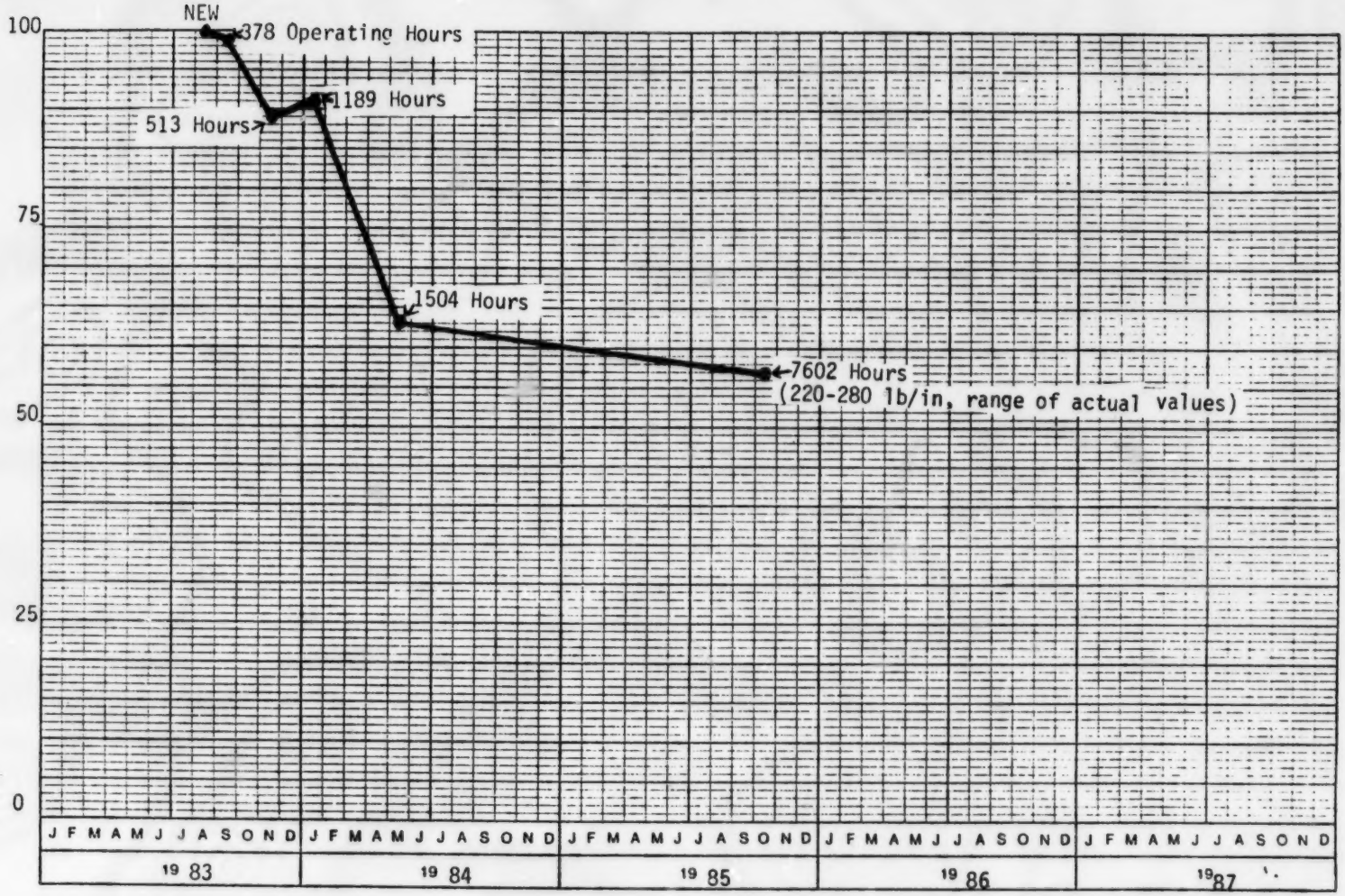
PERMEABILITY


NEW
100
75
50
25
0
RETAINED PERMEABILITY, %
378 Operating Hours
513 Hours
1189 Hours
1504 Hours
After 30" Vacuuming
7602 Hours
(20.5-39.9 ft/min, range of actual values)
After 10" Vacuuming
(10.8-30.4 ft/min, range of actual values)
As Received
(3.5-5.1 ft/min, range of actual values)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1983
1984
1985
1986
1987

INSTALLED - EXPOSURE TIME

Figure 7

TENSILE - WARP FIBERS


NEW
378 Operating Hours
513 Hours
1189 Hours
1504 Hours
7602 Hours
(220-280 lb/in, range of actual values)
100
75
50
25
0
RETAINED FABRIC STRENGTH, %
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1983
1984
1985
1986
1987
INSTALLED - EXPOSURE TIME

Reproduced from best available copy.

Figure 8

TENSILE - FILL FIBERS

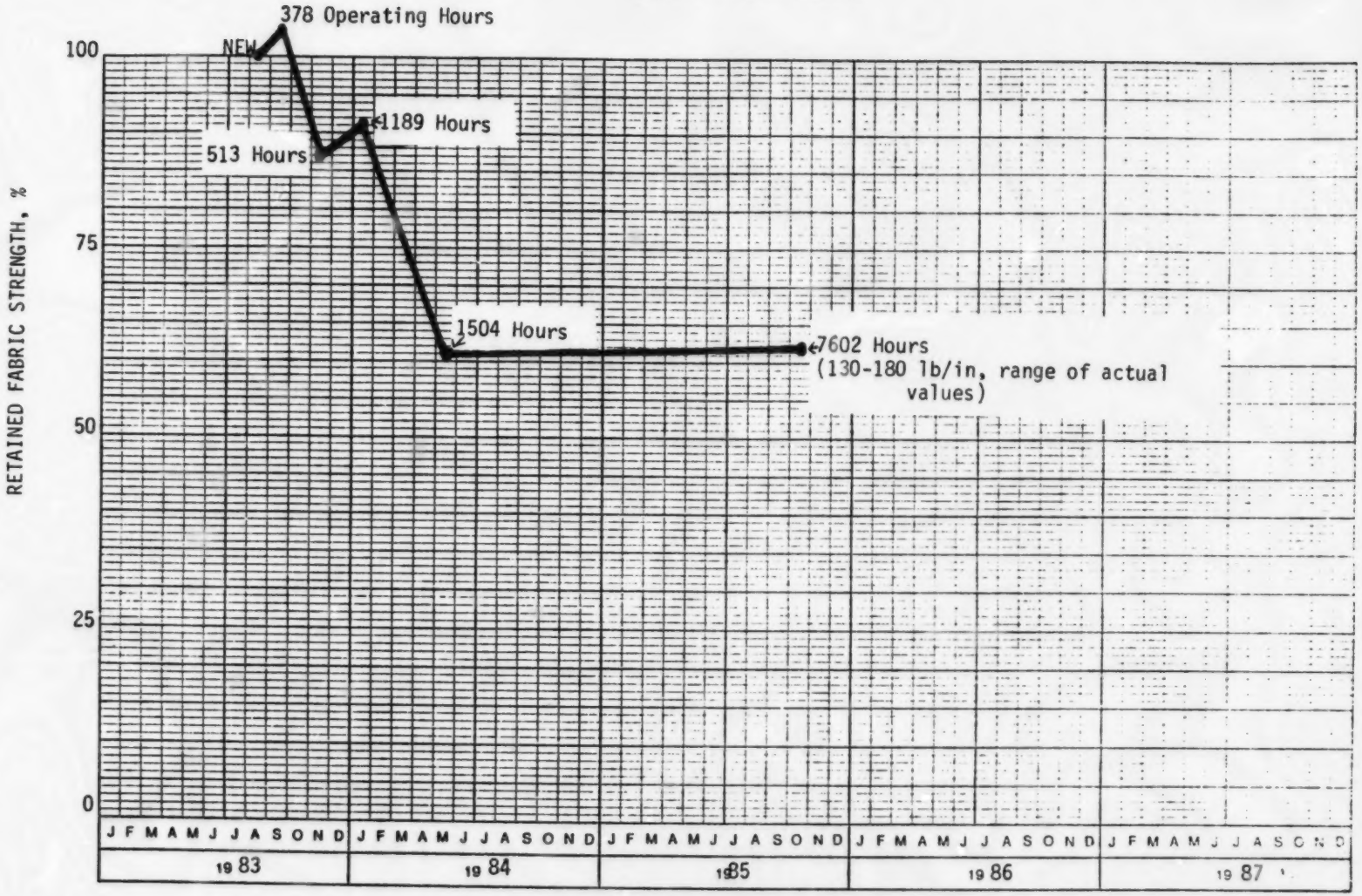


Figure 9

MULLEN BURST

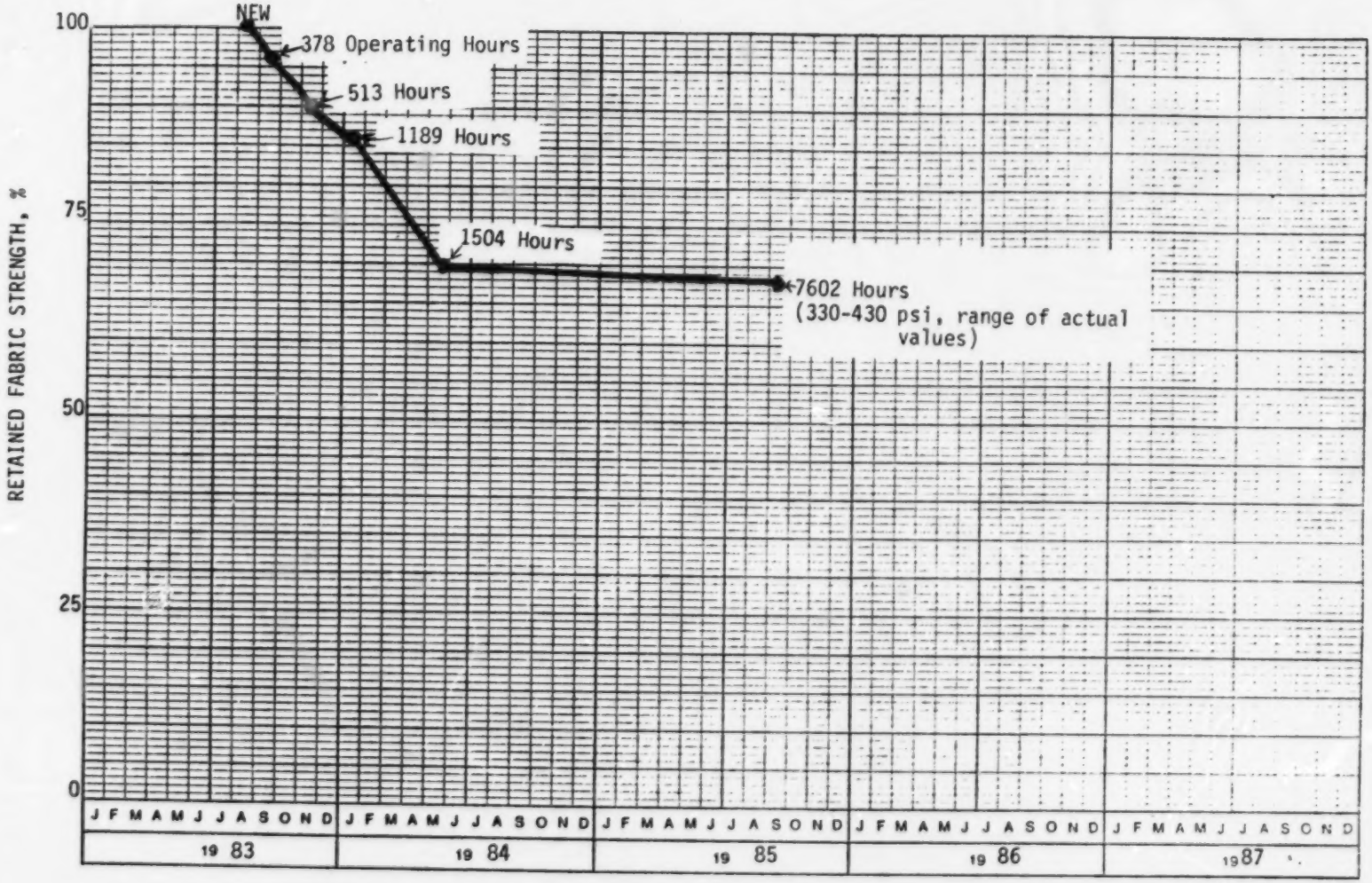

NEW
378 Operating Hours
513 Hours
1189 Hours
1504 Hours
7602 Hours
(330-430 psi, range of actual values)
100
75
50
25
0
RETAINED FABRIC STRENGTH, %
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
19 83
19 84
19 85
19 86
19 87
INSTALLED - EXPOSURE TIME

Figure 10

MIT FLEX - WARP FIBERS

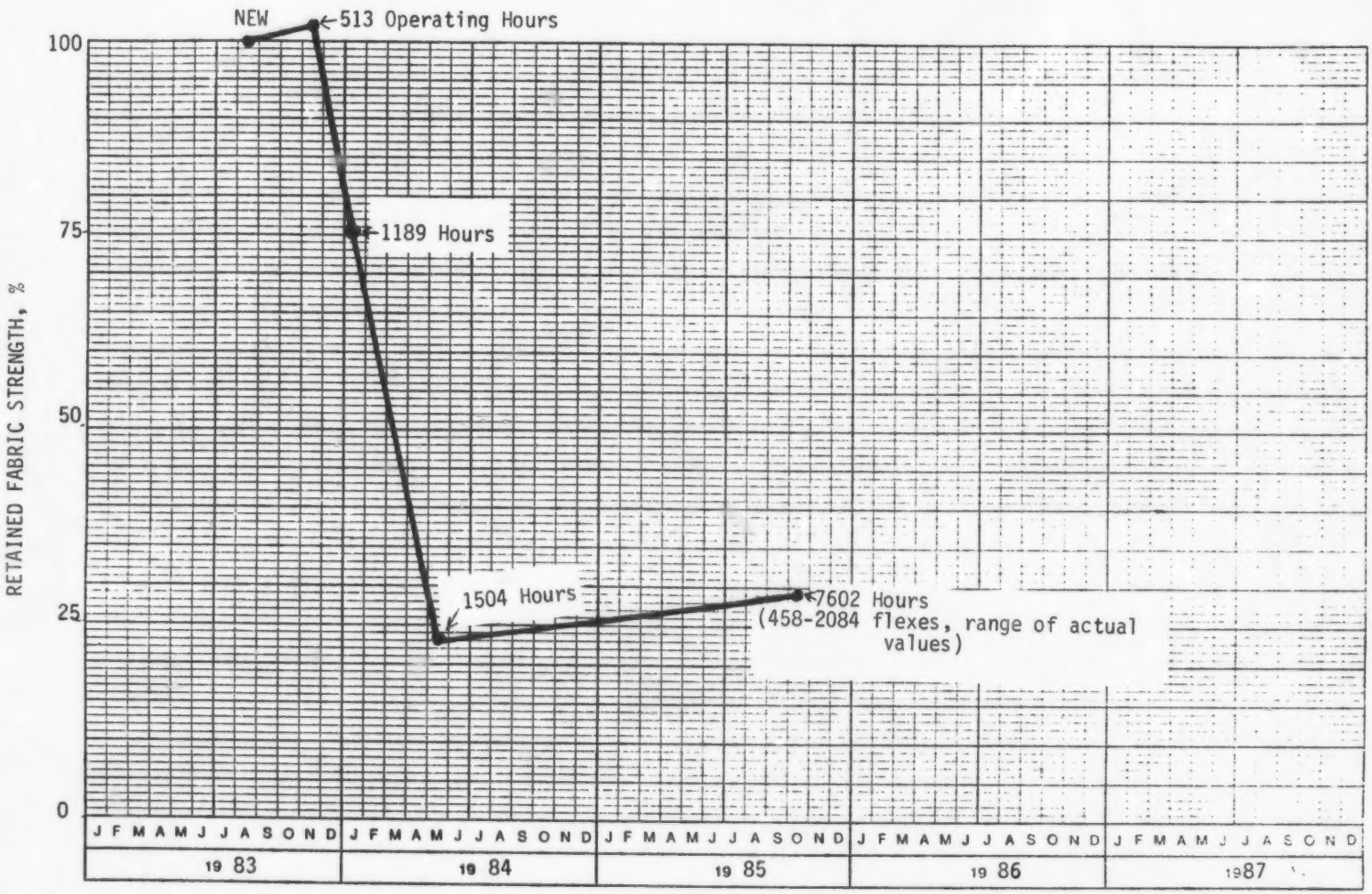
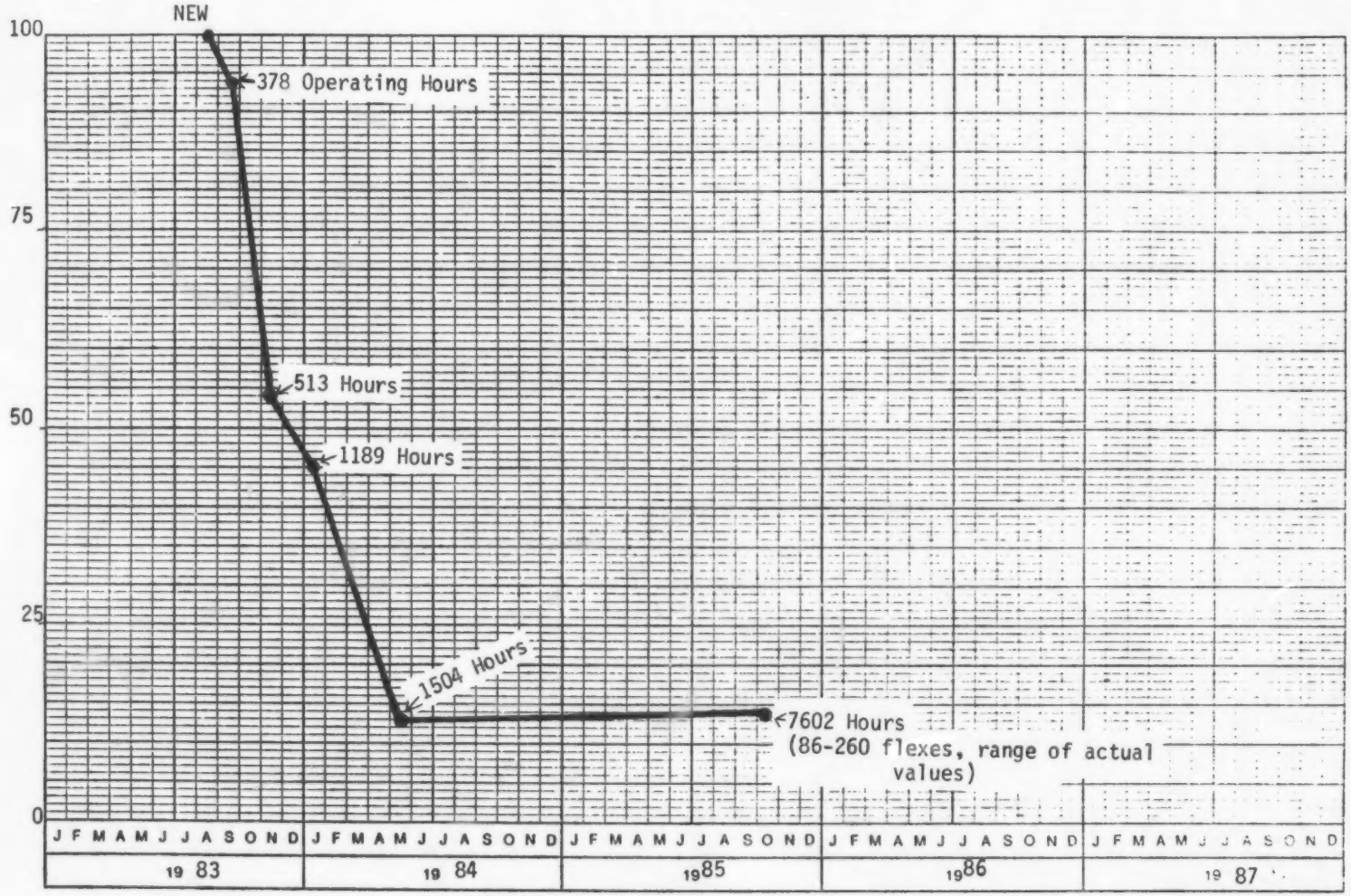


Figure 11

MIT FLEX - FILL FIBERS



EFFECT OF POSITION AND LENGTH OF EXPOSURE ON FABRIC

In order to test for differences among fabric test values for bags near module centers, Table V was prepared from the data contained in Table II. Although statistical tests (see the Appendix) indicated that there were separate but interacting effects on fabric test values due to length of exposure time and position in the baghouse, Table V demonstrates that the effect due to position probably was not the major reason for differences among fabric test values: The most obvious difference between values for bags near doors and bags near module centers was in MIT Flex values for fill fibers. Table VI, also derived from data in Table II, shows the more obvious effect due to length of exposure time on fabric characteristics. It is evident from Table VI that tests of fabric strength (Mullen Burst, Tensile Strength and MIT Flex), particularly for fill fibers, declined steadily with exposure time.

Baghouse 108 was used intermittently and the bags were subject to some deterioration even though the baghouse might not be operating. Installed bag life consists of operating time plus idle time. Installed bag life in excess of three years was observed for Baghouse 108, and although fill fiber strength after 7,600 hours of operation had deteriorated to the point of breakage at fewer than 100 flexes, still the bags appeared to occupy the

TABLE V

INVESTIGATION OF THE EFFECT OF POSITION ON FABRIC TEST VALUES

		Permeability, ft/min			Mullen Burst,	Tensile Strength, lb/in		MIT Flex		LOI, %
		As Rec'd	10" Vac	30" Vac	psi	Warp	Fill	Warp	Fill	
A	Module 2[a]	4.6	22.2	31.9	477	372	201	3444	591	3.8
A	Module 3[b]	4.7	21.4	31.4	466	368	185	3525	637	4.0
A	Module 6[c]	5.2	24.4	32.5	481	520	192	3681	636	4.2
B	Module 2[d]	4.8	22.9	31.9	468	390	204	4000	538	3.2
B	Module 4[e]	4.1	24.8	39.8	465	388	204	3624	469	3.8
B	Module 5[f]	4.1	18.3	27.9	462	391	214	5135	589	3.4

A = Test values of bags from locations near doors.

B = Test values of bags from locations near module centers.

[a] Averages of test values for bags 626DB, 773DB, 819DB, 1096DB.

[b] Averages of test values for bags 623DB, 775DB, 820DB, 1098DB.

[c] Averages of test values for bags 622DB, 776DB, 821DB, 1092DB.

[d] Averages of test values for bags 621DB, 774DB, 818DB, 1099DB.

[e] Averages of test values for bags 629DB, 777DB, 822DB, 1094DB.

[f] Averages of test values for bags 627DB, 780DB, 823DB, 1095DB.

TABLE VI

INVESTIGATION OF THE EFFECT OF LENGTH OF EXPOSURE ON FABRIC TEST VALUES

		Permeability, ft/min			Mullen Burst,	Tensile Strength, lb/in		MIT Flex		
		As Rec'd	10" Vac	30" Vac	psi	Warp	Fill	Warp	Fill	LOI, %
A	Module 2[a]	4.6	22.2	31.9	477	372	201	3444	591	3.8
	Module 2[b]	4.1	10.8	20.5	386	265	155	2084	261	
	Module 3[a]	4.7	21.4	31.4	466	368	185	3525	637	4.0
	Module 3[c]	5.1	16.5	32.1	369	270	180	1108	172	
	Module 6[a]	5.2	24.4	32.5	481	520	192	3681	636	4.2
	Module 6[d]	4.1	10.9	22.2	359	224	133	1092	157	
B	Module 2[a]	4.8	22.9	31.9	468	390	204	4000	538	3.2
	Module 2[e]	4.1	15.7	27.6	432	267	152	1090	185	
	Module 4[a]	4.1	24.8	39.8	465	388	204	3624	469	3.8
	Module 4[f]	5.5	30.4	39.9	359	269	137	458	106	
	Module 5[a]	4.1	18.3	27.9	462	391	214	5135	589	3.4
	Module 5[g]	4.0	23.2	33.6	342	280	148	736	86	

A = Test values of bags from locations near doors.

B = Test values of bags from locations near module centers.

[a] Average of 4 test values, one value for the bag in each Series (I-IV) from the same position in the baghouse.

[b] Test values for bag 2223DB (7600 hours of exposure).
[c] Test values for bag 2222DB (7600 hours of exposure).
[d] Test values for bag 2219DB (7600 hours of exposure).
[e] Test values for bag 2215DB (7600 hours of exposure).
[f] Test values for bag 2217DB (7600 hours of exposure).
[g] Test values for bag 2218DB (7600 hours of exposure).

plateau in bag life. That remained true in July 1986; six months after the last bag pull, there were no visible emissions or flange-to-flange pressure drop problems with Baghouse 108.

POWER COSTS

Operating costs for the induced draft (I. D.) and Reverse Air (RA) fans were calculated using actual hours of operation during 1983, 1984 and 1985, and VEPCO-quoted cost of electricity.

Power Costs for I. D. and RA Fans

Fan Power[2] P (in kWh) = $Q \times [0.7457/(6356 \times E)] \times \Delta P \times H$

where Q = gas flow, ACFM

0.7457 = constant (1 hp = 0.7457 kW)

E = fan efficiency (assumed to be 60%)

ΔP = pressure drop across the device, inches H_2O

H = annual operating hours.

Fan Power Cost = P x ($/kWh).

I.D. Fan Data

Baghouse 108 inlet average gas flow at full boiler load (data from acceptance tests, 12/10/83)[1]: 47,561 ACFM @ 371°F.

I.D. fan power cost was calculated using the representative inlet volume of 50,000 ACFM @ 370°F. Baghouse 108 flange-to-flange pressure drop normally ran 2-4 inches H_2O.

RA Fan Data

The calculation assumed an RA gas flow of 10,000 ACFM. RA fan power costs were calculated for pressure drops across the RA fan of 0.5, 1.0 and 1.5 inches H_2O.

Baghouse 108 Operating Hours

1983 -- 1519 hours

1984 -- 4081 hours

1985 -- 2002 hours as of last bag pull

Cost of Electricity for NAB, Little Creek, VA

April 1986 quotation by VEPCO for industrial power cost in Norfolk, VA (schedule 6, Virginia jurisdiction): $0.045446/kWh.

ANNUAL FAN POWER COSTS

System ΔP,	I. D. Fan			RA Fan			RA ΔP,
inches H_2O	1983	1984	1985	1983	1984	1985	inches H_2O
2	$1350	$3627	$1779	$ 67	$ 181	$ 89	0.5
3	2025	5440	2669	135	363	178	1.0
4	2700	7253	3558	202	544	267	1.5

Fan Power Costs

If full-time operation of the baghouse were assumed, (fifty weeks a year, seven days a week, twenty-four hours a day, giving 8400 hrs/yr), with a flow of 50,000 ACFM through the unit at a pressure drop of four inches, the induced draft fan power cost would be $14,929 per year and each inch of pressure drop would cost $3,732.

CONCLUSIONS

Acceptance tests conducted on Baghouse 108 during December 1983[1], after about five months of operation, indicated that the baghouse was operating within compliance levels; however, the tested particulate removal efficiency of 95% did not meet the Navy specification[4] of >99% efficiency. Analysis of test bags suggested leakage within the baghouse which would certainly contribute to lowered removal efficiency. Visible emissions were not a problem as they always were <20% during acceptance tests. As of July 1986, visible emissions were still not a problem with Baghouse 108.

There appeared to be progressive but not catastrophic loss of fabric strength, particularly for fill fibers, over the course of the fabric testing period. Both length of exposure time and position in the baghouse had an effect on the loss of fabric strength. Raw data from the MIT Flex tests indicated serious potential for failure (i. e., fabric failure at about 100 flexes), of fill fibers for bags from Series IV (approximately 1500 hours of exposure) and Series V (approximately 7600 hours of exposure). There were, however, few differences in Flex test results for those two series despite the great difference in exposure time, and that suggested the possibility of a long plateau in useful bag life. Since it is not known exactly how long the plateau might last, quarterly testing of the bags should be employed if a spare set of bags were not in place. Almost all of the original bag set remained in service as of July 1986, more than three years after baghouse start-up, without visible emissions or flange-to-flange pressure drop problems.

REFERENCES

1. ETS, Inc., Roanoke, VA for SMS Mechanical Contractors. Baghouse Performance Tests, Units 107 & 108, Central Steam Plant, NAB, Little Creek, VA, December 9 & 10, 1983. ETS Contract No. 82-263-T, 1983.

2. Edmisten, N. G. and F. L. Bunyard. "A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources," JAPCA, V 20, N 7, July 1970.

3. Walpole, Ronald E. and Raymond H. Myers. Probability and Statistics for Engineers and Scientists, 2nd Edition. Macmillan Publishing Co., New York, 1978.

4. Navy Specification 05-79-9134, Section 15605, Boiler Baghouse.

APPENDIX

STATISTICAL ANALYSIS

REPORT OF ANALYSIS OF VARIANCE TESTS

FOR THE NAB, LITTLE CREEK, VA

A two-factor analysis of variance (ANOVA) test[3] using exposure time as the first factor and position in the baghouse as the second factor, was performed on data from each of these fabric tests:

Permeability as received

Permeability after 10" vacuuming

Permeability after 30" vacuuming

Mullen Burst

Tensile Strength (warp fibers)

Tensile Strength (fill fibers)

MIT Flex (warp fibers)

MIT Flex (fill fibers)

PURPOSE: To test for significant effects from exposure time and position in the baghouse on results from each of the fabric tests, and for significant interaction between those effects.

OVERALL CONCLUSIONS: Generally, exposure time and position in the baghouse had significant effects on fabric test results, and there was significant interaction between the exposure and position effects.

The effects due to exposure time, position in the baghouse, and their interaction, were all insignificant only for the Permeability As Received data. The effect of position in the baghouse was insignificant only for Mullen Burst data.

DATA

Effect A = exposure time

A1 = Series I bags (621DB - 629DB)

A2 = Series III bags (772DB - 780DB)

A3 = Series IV bags (1092DB - 1103DB)

Effect B = position in the baghouse

B1 = Module 2 Compartment C Bag 10 (626DB, 819DB, 1096DB)

B2 = Module 2 Compartment F Bag 5 (621DB, 818DB, 1099DB)

B3 = Module 3 Compartment C Bag 10 (623DB, 820DB, 1098DB)

B4 = Module 3 Compartment F Bag 5 (625DB, 824DB, 1097DB)

B5 = Module 6 Compartment C Bag 10 (622DB, 821DB, 1092DB)

B6 = Module 6 Compartment F Bag 5 (624DB, 825DB, 1093DB)

B7 = Module 4 Compartment F Bag 5 (629DB, 822DB, 1094DB)

B8 = Module 5 Compartment F Bag 5 (627DB, 823DB, 1095DB)

Replication = area of bag tested

N1 = top

N2 = middle

N3 = bottom

RESULTS

Two-Factor ANOVA

Fabric Test	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed F
Permeability As Received	Exposure	9.29	2	4.64	1.82
	Position	17.51	7	2.50	0.98
	Interaction	57.93	14	4.14	1.62
	Error	122.75	48	2.56	
	Total	207.48	71		
Permeability after 10" vacuuming	Exposure	498.27	2	249.14	12.47
	Position	426.23	7	60.89	3.05
	Interaction	2099.99	14	150.00	7.51
	Error	959.26	48	19.98	
	Total	3983.74	71		
Permeability after 30" vacuuming	Exposure	2727.94	2	1363.97	75.12
	Position	1210.38	7	172.91	9.52
	Interaction	5294.24	14	378.16	20.83
	Error	871.51	48	18.16	
	Total	10104.08	71		
Mullen Burst	Exposure	282937.86	2	141468.93	144.0
	Position	2478.38	7	354.05	0.36
	Interaction	27161.92	14	1940.14	1.98
	Error	47151.33	48	982.32	
	Total	359729.49	71		

RESULTS, continued

Two-Factor ANOVA

Fabric Test	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Computed F
Tensile Strength (warp fibers)	Exposure	302456.19	2	151228.10	189.1
	Position	20881.88	7	2983.12	3.73
	Interaction	49088.25	14	3506.30	4.38
	Error	38393.83	48	799.87	
	Total	410820.15	71		
Tensile Strength (fill fibers)	Exposure	129951.03	2	64975.51	249.4
	Position	10711.06	7	1530.15	5.87
	Interaction	18005.86	14	1286.13	4.94
	Error	12505.33	48	260.53	
	Total	171173.28	71		
MIT Flex (warp fibers)	Exposure	571748328.08	2	285874164.04	572.4
	Position	20553439.82	7	2936205.69	5.88
	Interaction	49520177.14	14	3537155.51	7.08
	Error	23970707.83	48	499389.75	
	Total	665792652.88	71		
MIT Flex (fill fibers)	Exposure	10040738.77	2	5020369.39	369.5
	Position	282360.11	7	40337.16	2.97
	Interaction	739990.84	14	52856.49	3.89
	Error	652135.00	48	13586.15	
	Total	11715224.72	71		

CRITICAL REGIONS

1. Critical Region for effect due to Exposure Time:

   For 95% assurance of a significant effect, computed F > 3.20 (2 and 48 degrees of freedom);

   for 99% assurance of a significant effect, computed F > 5.10 (2 and 48 degrees of freedom).

2. Critical Region for effect due to Position in the Baghouse:

   For 95% assurance of a significant effect, computed F > 2.22 (7 and 48 degrees of freedom);

   for 99% assurance of a significant effect, computed F > 3.05 (7 and 48 degrees of freedom).

3. Critical Region for interaction between Exposure and Position effects:

   For 95% assurance of a significant effect, computed F > 1.92 (14 and 48 degrees of freedom);

   for 99% assurance of a significant effect, computed F > 2.50 (14 and 48 degrees of freedom).

CONCLUSIONS

1. Fabric test: Permeability As Received

   There was no evidence, at either 95% or 99% assurance, of significant effects due to exposure time or position in the baghouse.

   There was no evidence of significant interaction between exposure time and position in the baghouse.

2. Fabric test: Permeability after 10" vacuuming

   There was evidence, at both 95% and 99% assurance levels, of a significant effect due to exposure time, and significant interaction between exposure time and position in the baghouse.

   There was evidence at 95% assurance, but not at 99%, of a significant effect due to position in the baghouse.

3. Fabric test: Permeability after 30" vacuuming

   There was evidence, at both 95% and 99% assurance levels, of significant effects due to exposure time and position in the baghouse, and significant interaction between those effects.

4. Fabric test: Mullen Burst

   There was evidence of a significant effect due to exposure time, but not due to position in the baghouse.

There was evidence at 95% assurance level, but not at 99%, of significant interaction between exposure time and position in the baghouse.

5. Fabric test: Tensile Strength (warp fibers)
   There was evidence, at both 95% and 99% assurance levels, of significant effects due to exposure time and position in the baghouse, and significant interaction between those effects.

6. Fabric test: Tensile Strength (fill fibers)
   There was evidence, at both 95% and 99% assurance levels, of significant effects due to exposure time and position in the baghouse, and significant interaction between those effects.

7. Fabric test: MIT Flex (warp fibers)
   There was evidence, at both 95% and 99% assurance levels, of significant effects due to exposure time and position in the baghouse, and significant interaction between those effects.

8. Fabric test: MIT Flex (fill fibers)
   There was evidence, at both 95% and 99% assurance levels, of a significant effect due to exposure time, and significant interaction between exposure time and position in the baghouse.

CONCLUSIONS, continued

There was evidence at 95% assurance level, but not at 99%, of a significant effect due to position in the baghouse.